

Simulation of the Radiative Properties of Ice Clouds, Snow, and Dust Aerosol in Support of CERES

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In collaboration with

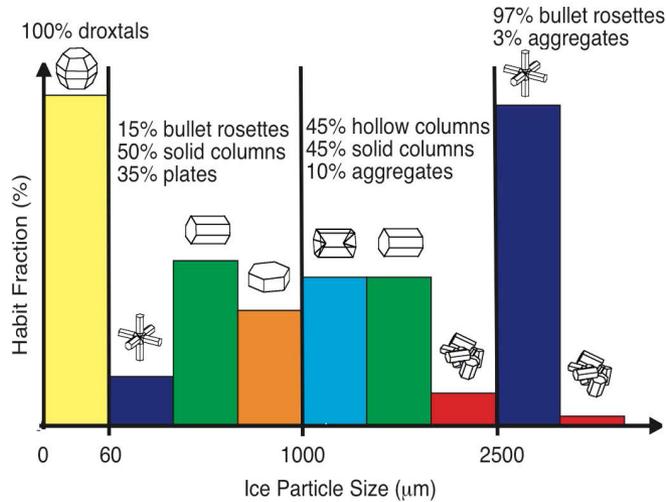
N. Loeb, P. Minnis, S. Kato, W. Smith Jr.,
S. Sun-Mack, G. Hong

Stephens, G. L., S.-C. Tsay, P. W. Stackhouse Jr., and P. J. Flatau, 1990: The relevance of the microphysical and radiative properties of cirrus clouds to climate and climatic feedback. *J. Atmos. Sci.*, **47**, 1742–1754.

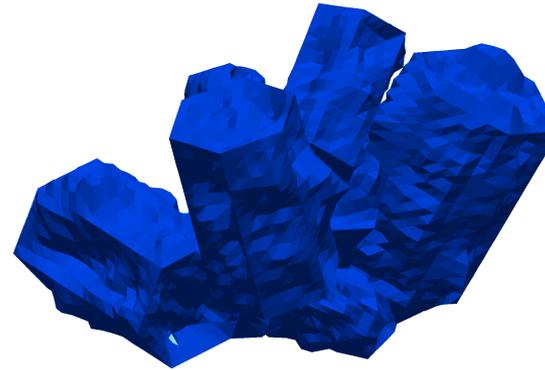
- “The asymmetry parameter had to be **adjusted from** the broadband Mie value of **$g=0.87$** for the size distribution chosen to a lower value of **$g=0.7$** in order to **bring the observations and theory into broad agreement.**”
- “Cirrus clouds characterized by **$g=0.87$** warmed **approximately twice** as much as cirrus clouds modeled **with $g=0.7$.**”

MODIS C5 (Baum et al. 2005) and MODIS C6 (Platnick et al. 2017) Ice Models

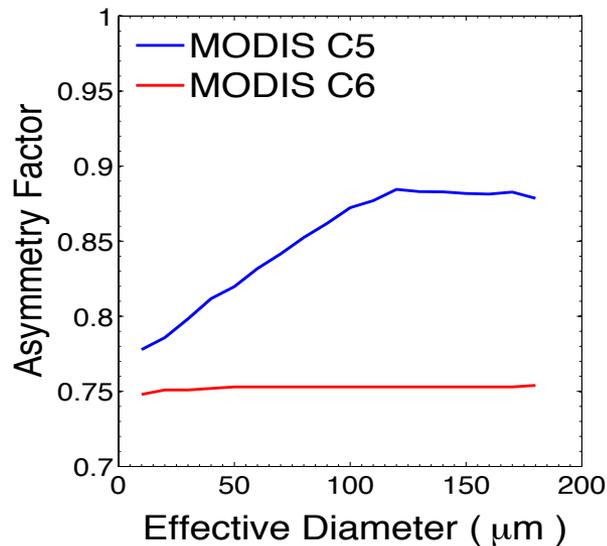
a. MODIS Collection 5



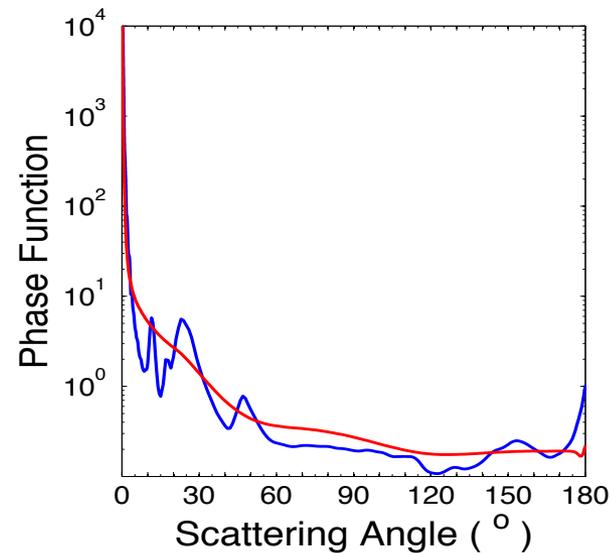
b. MODIS Collection 6



c.

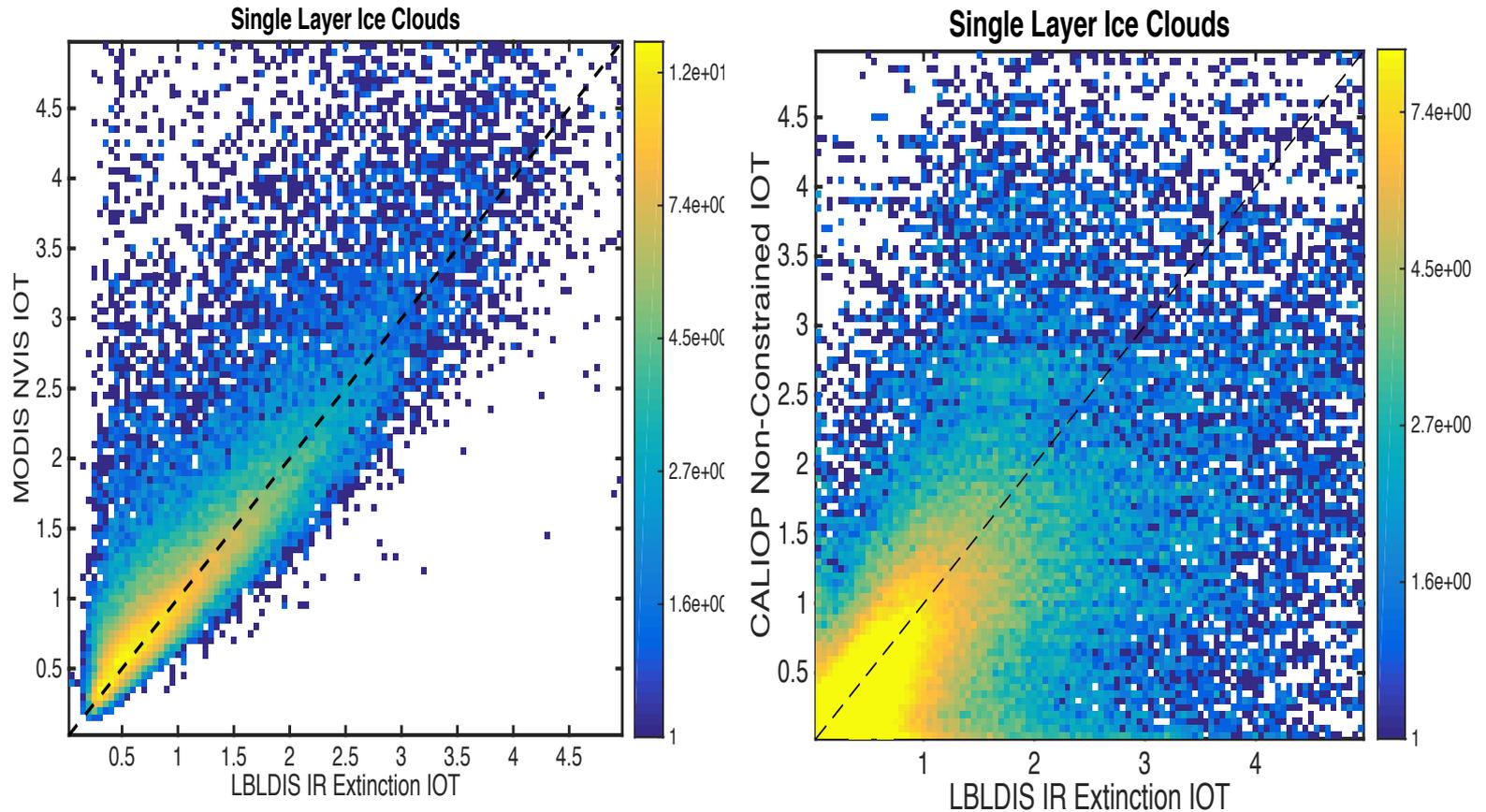


d.



MODIS C6 versus CALIPSO Ice Cloud Optical Thickness (IOT)

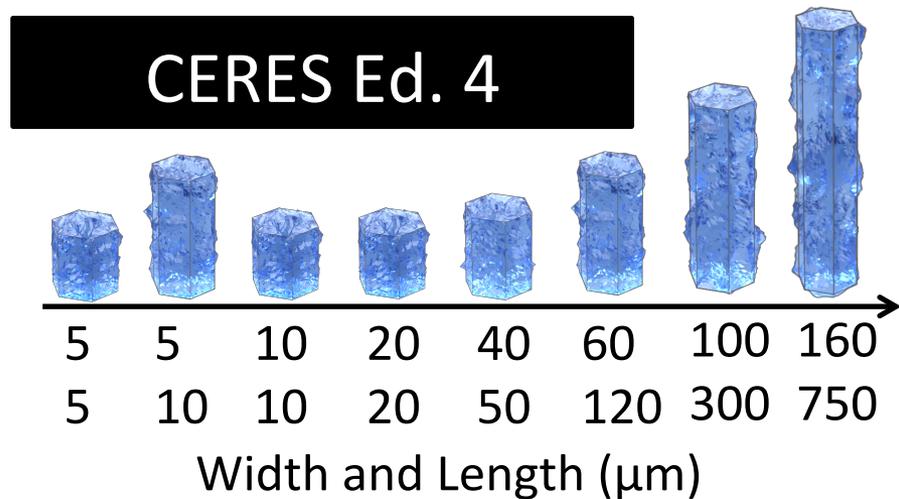
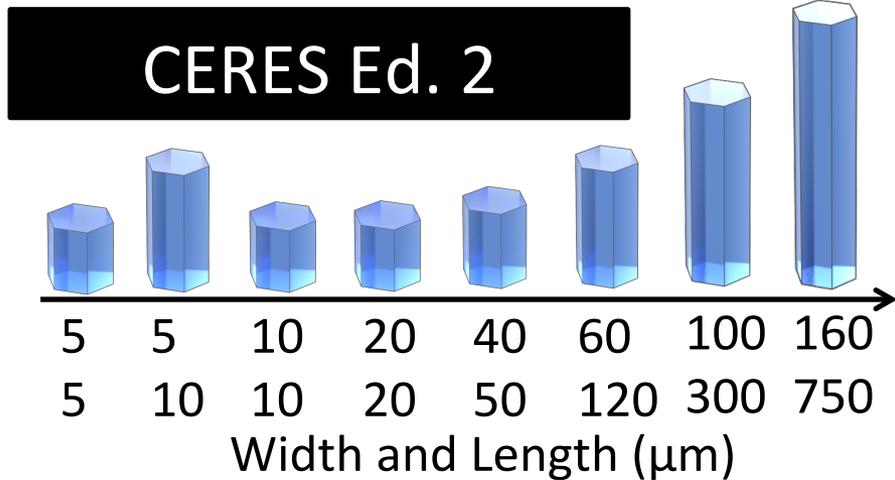
Holz et al., 2015



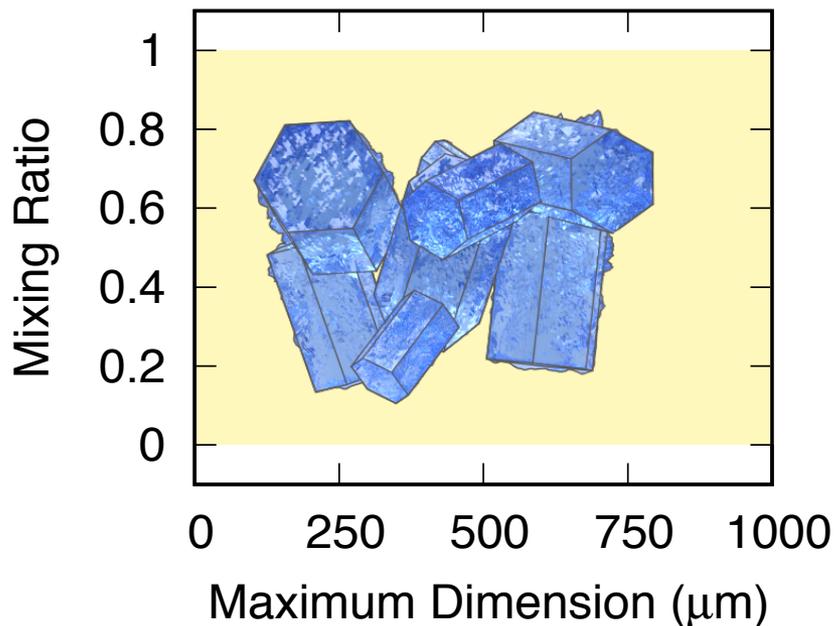
Left: the joint histogram comparing the MODIS C6 ice optical thickness (IOT) with the reference IR IOT retrieval. Right: the CALIOP non-constrained IOT using a modified lidar ratio of 32 is compared to collocated IR MODIS retrieved IOT.

Ice Cloud Simulations

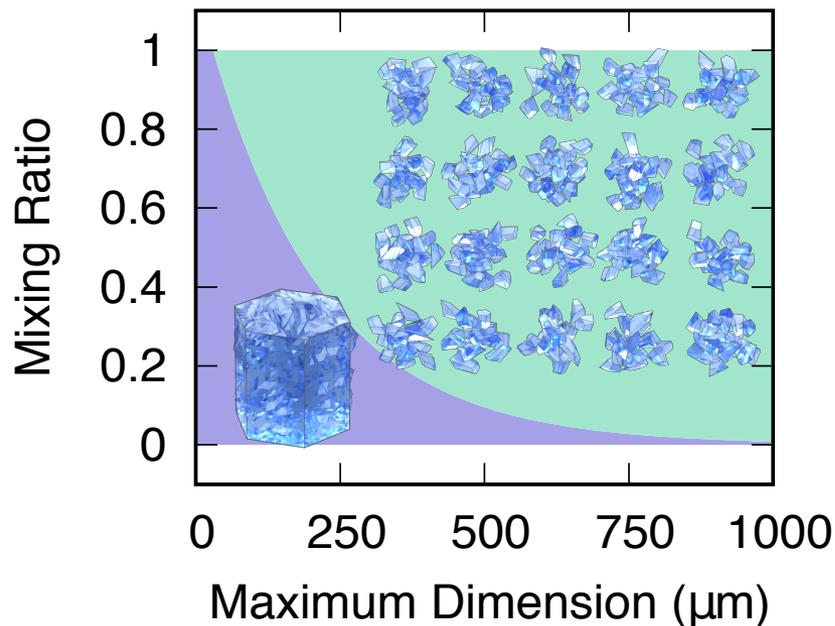
Particle Shapes and Mixing Ratios



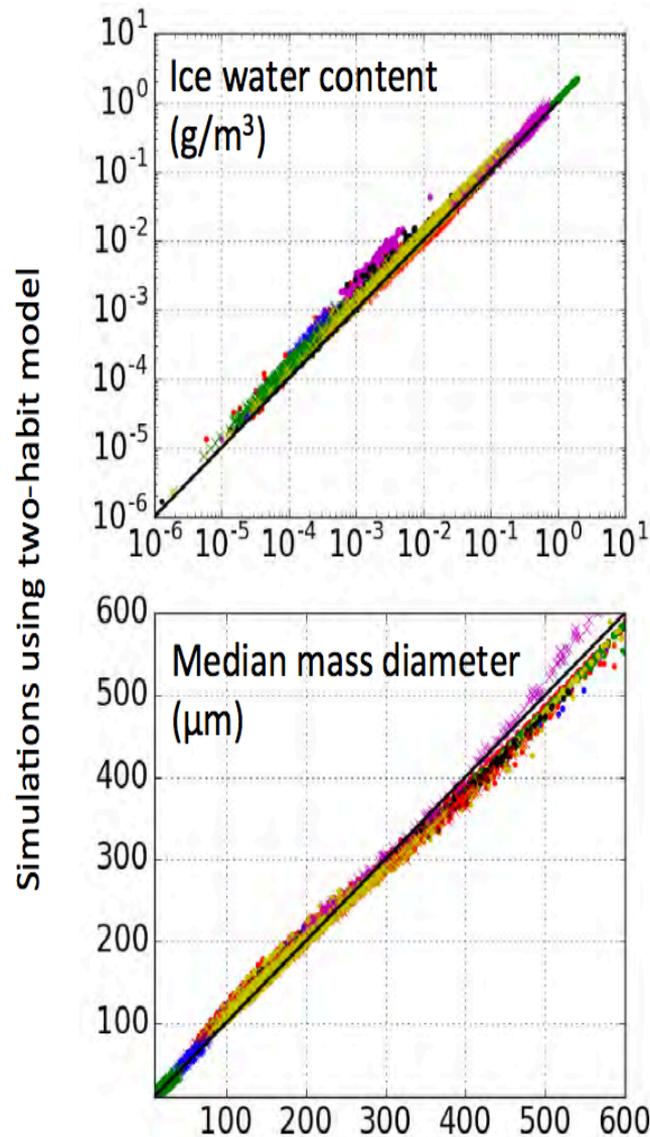
MODIS Collection 6



Two-habit



Consistency of THM with in-situ microphysics measurement

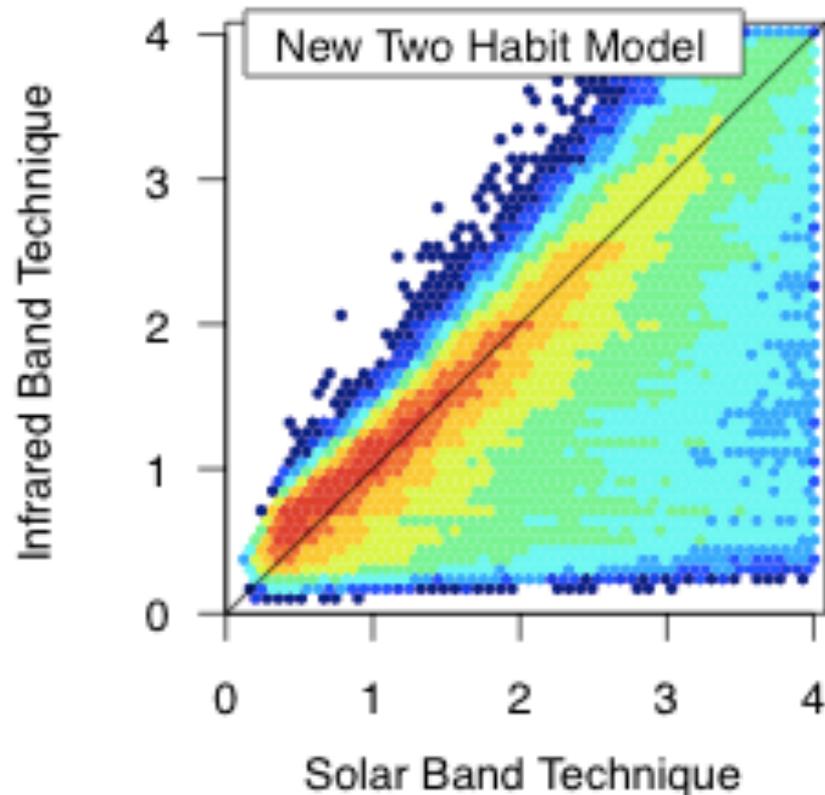


In-situ Measurements (Heymsfield et al, 2013)

- ACTIVE Hector
- ACTIVE Monsoon
- ACTIVE SquallLine
- ARM-IOP
- CRYSTAL
- MIDCIX
- MPACE
- preAVE
- SCOUT
- TC4
- TRMM

Spectral consistency

Comparison between the the cloud optical thickness retrieved by the solar band technique and that by the infrared band technique



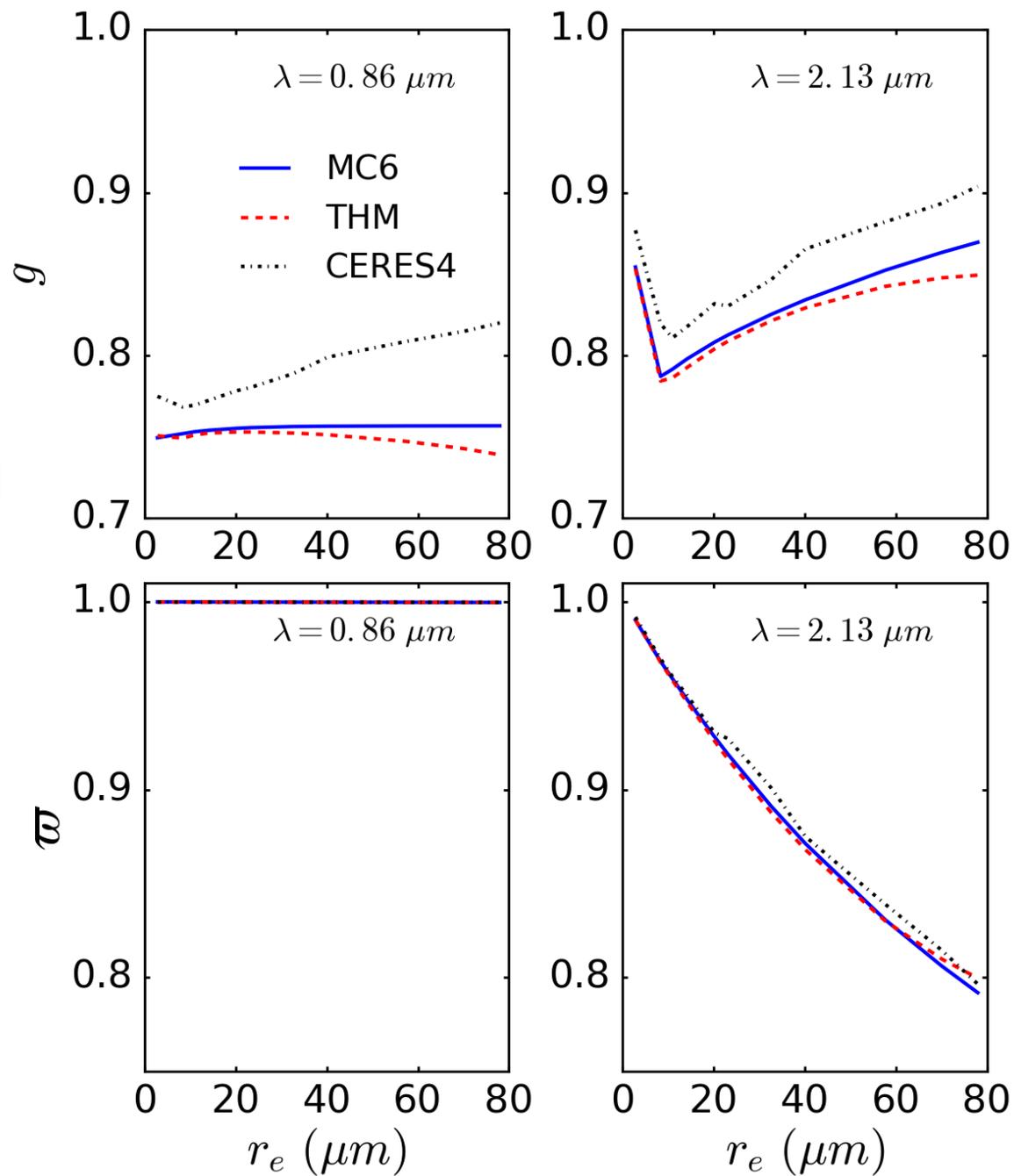
Ice Cloud Simulations

Asymmetry Parameter

The THM has smaller asymmetry parameter than the CERES 4 model

Single Scattering Albedo

The THM has slightly smaller single scattering albedo than CERES 4 model at 2.1 μm Channel

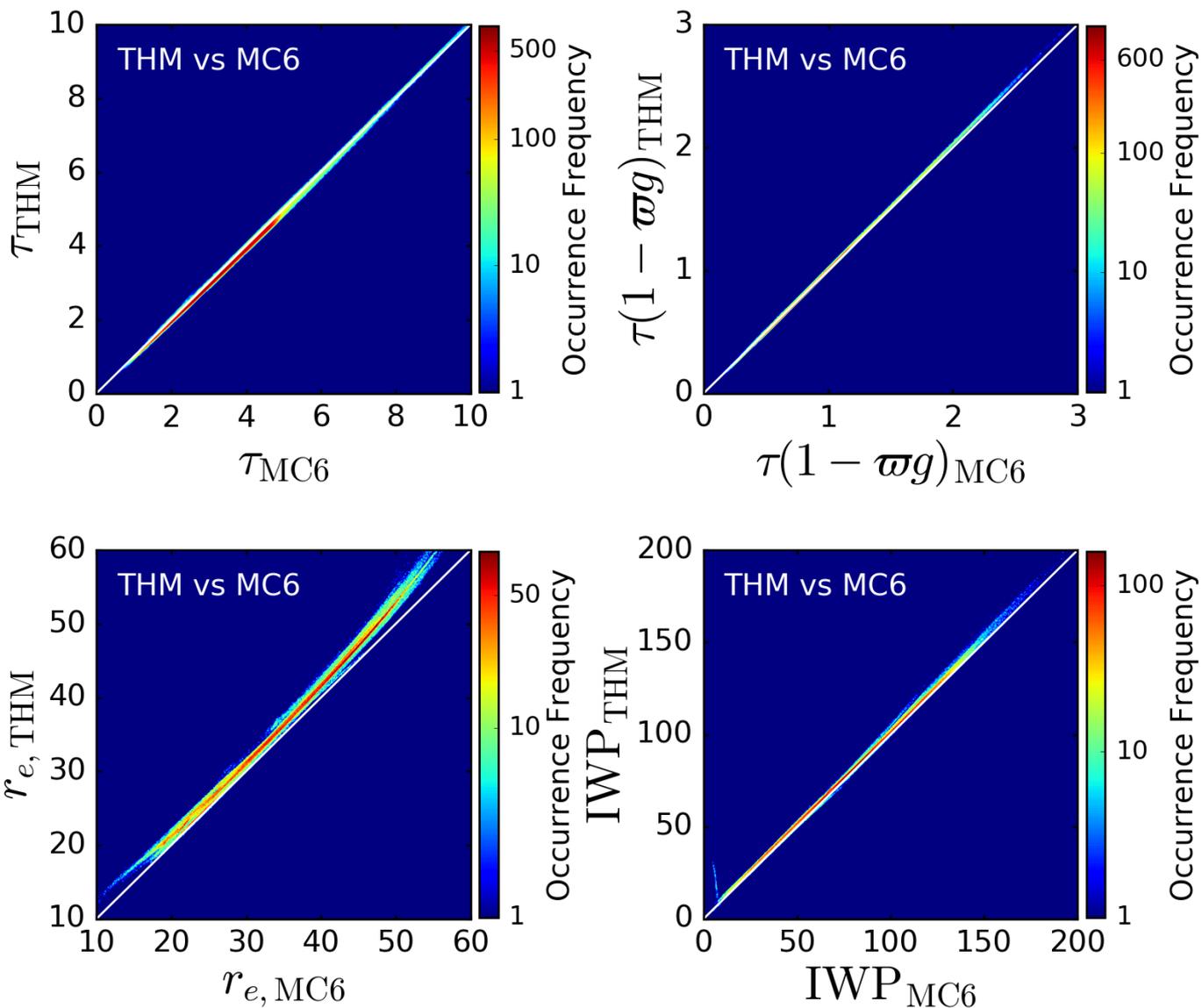


Ice Cloud Simulations

THM: Two-habit

MC6: MODIS Collection 6

Retrieved ice cloud optical thickness (τ), effective optical thickness $\tau(1-\omega g)$, effective radius (r_e), and ice water path (IWP) from MODIS Level 1B radiance

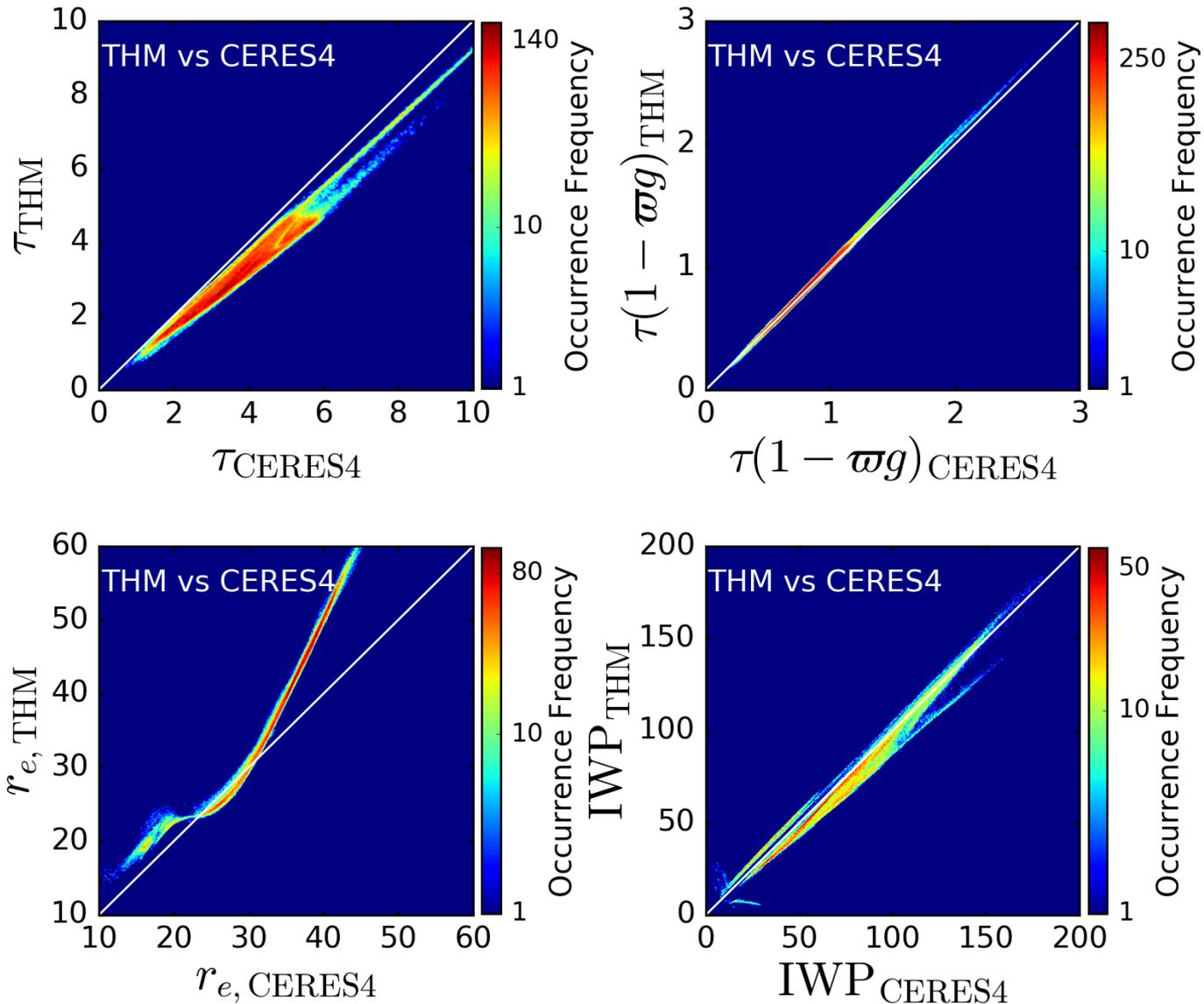


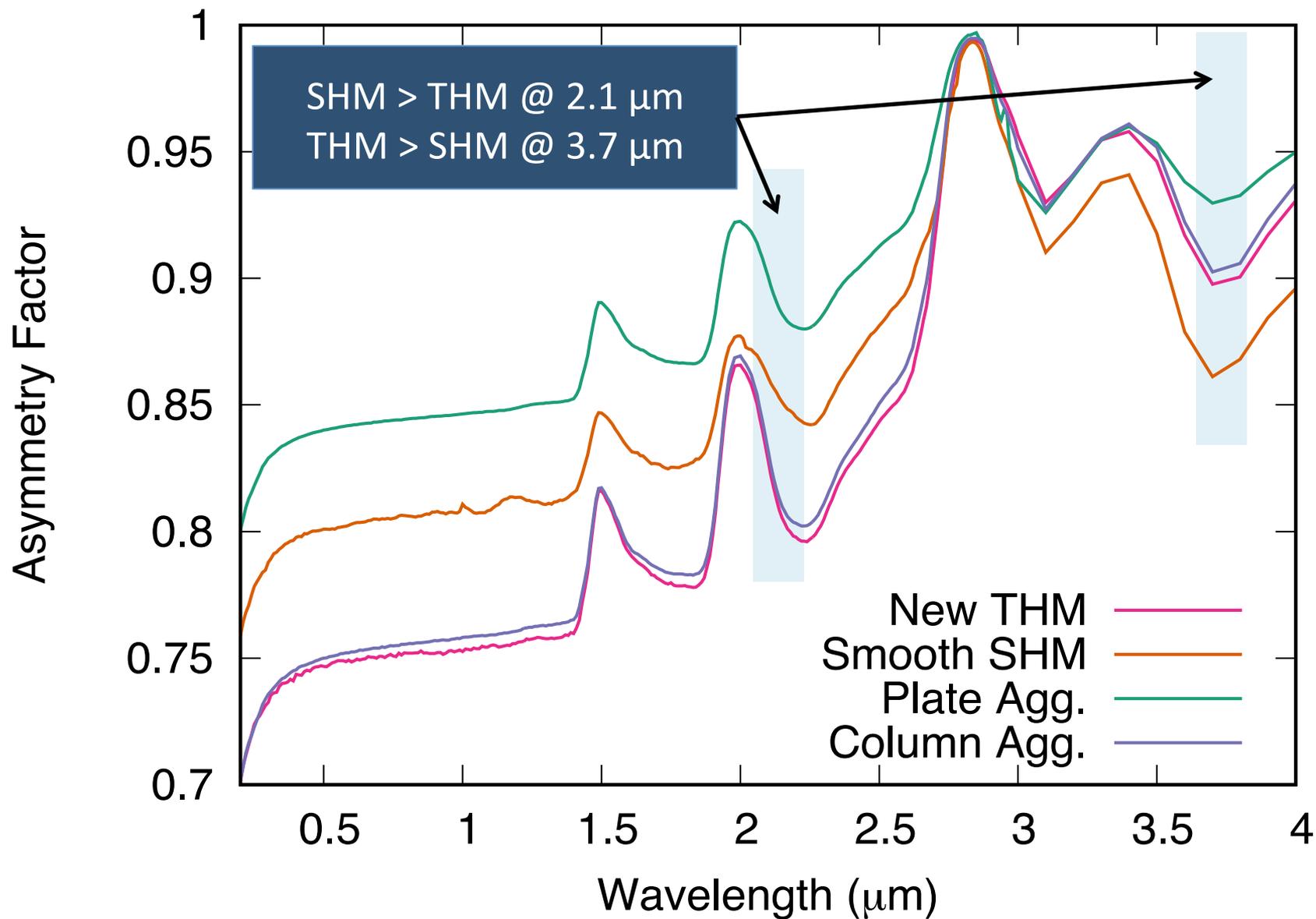
Ice Cloud Simulations

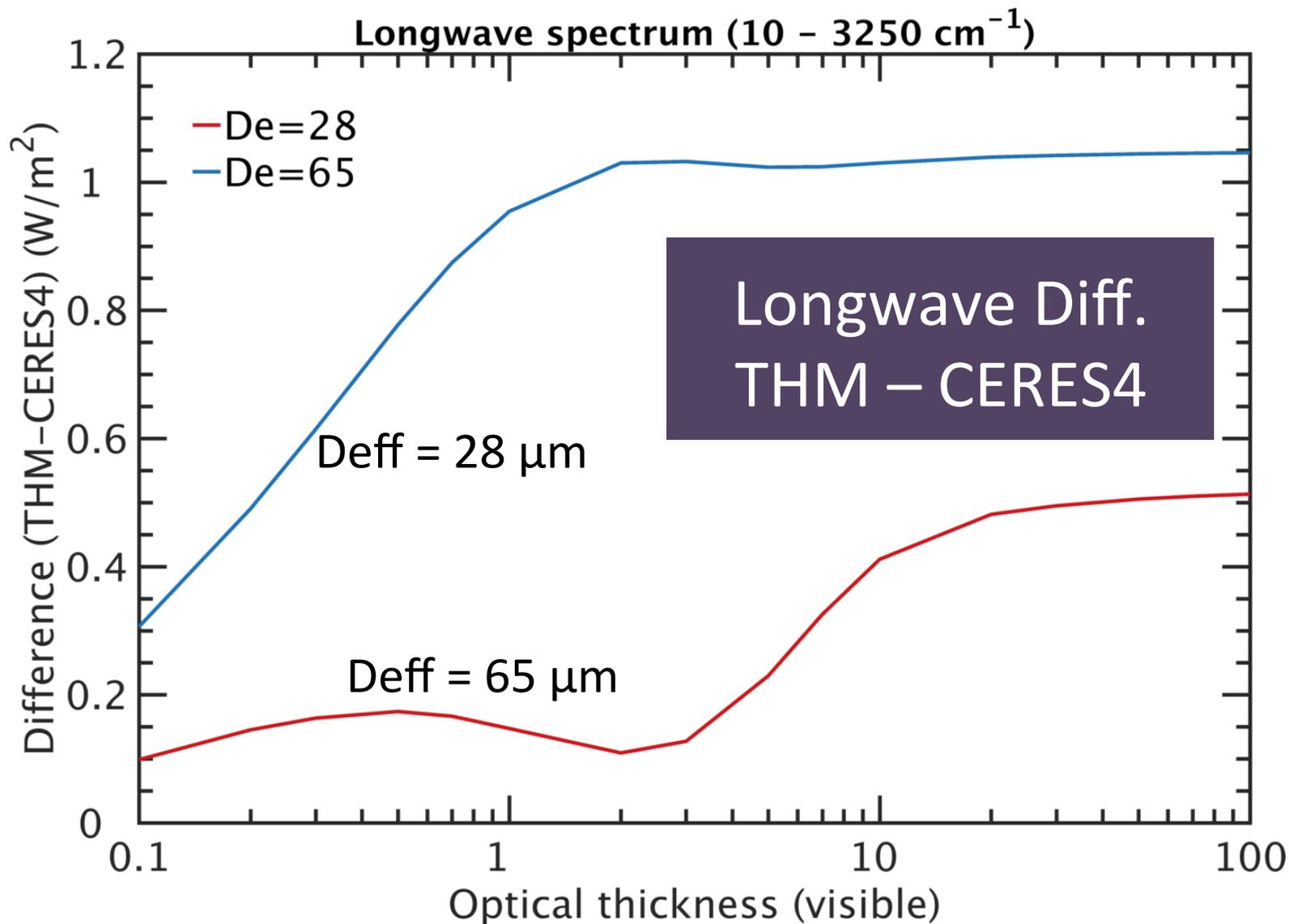
Retrieved ice cloud optical thickness (τ), effective optical thickness $\tau(1-\omega_g)$, effective radius (r_e), and ice water path (IWP) from MODIS Level 1B radiance

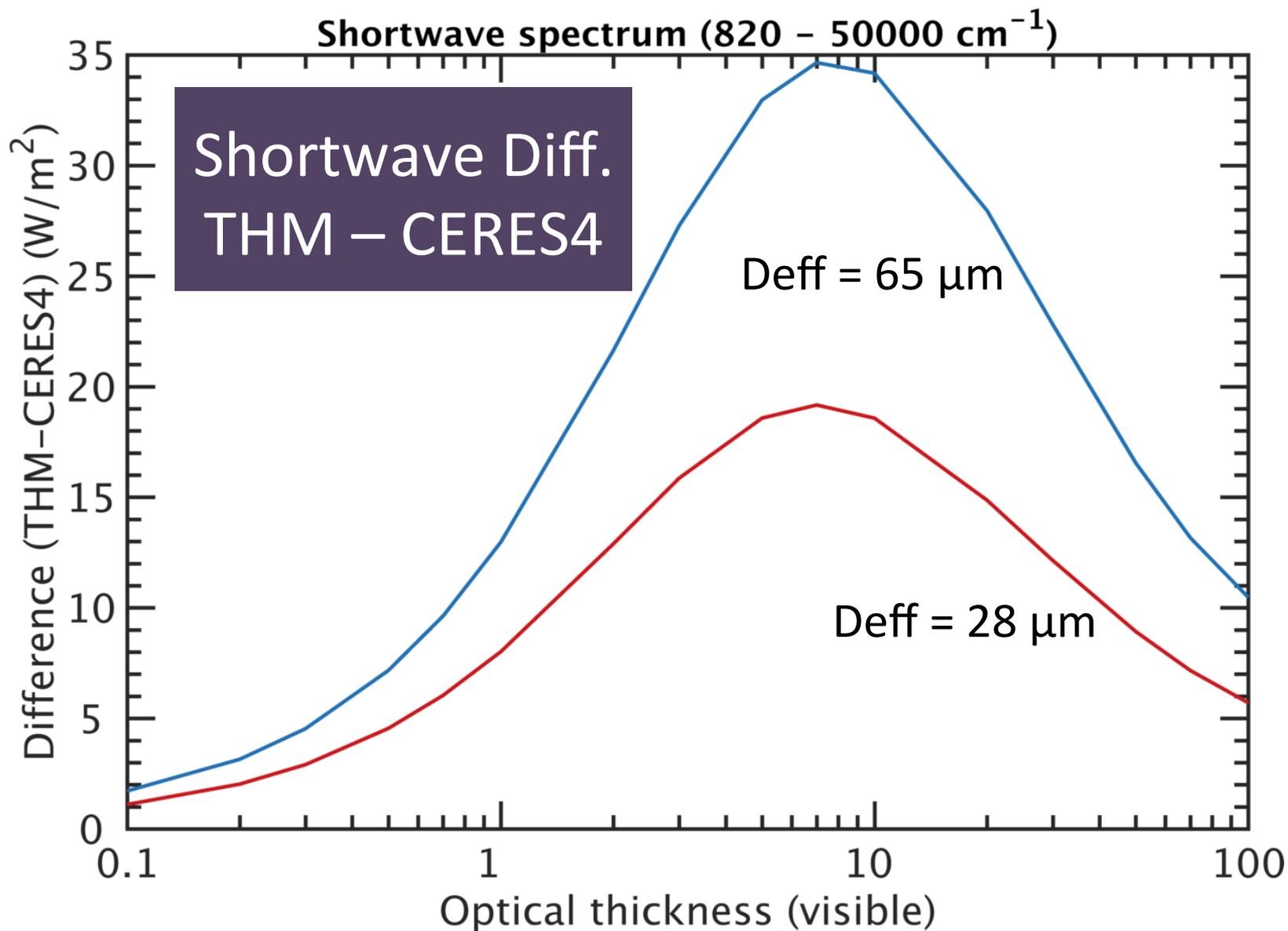
THM: Two-habit

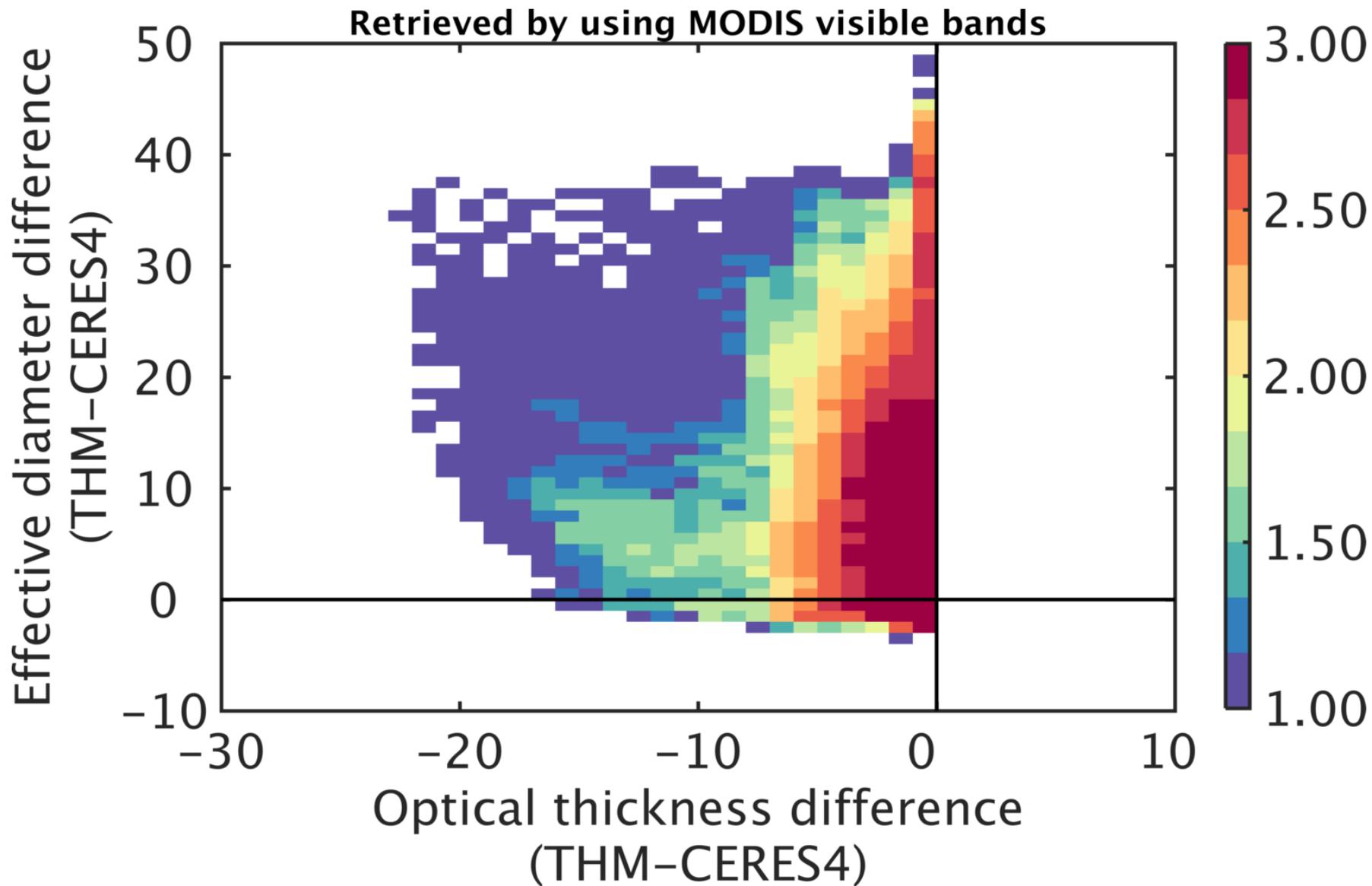
CERES4: CERES Edition 4



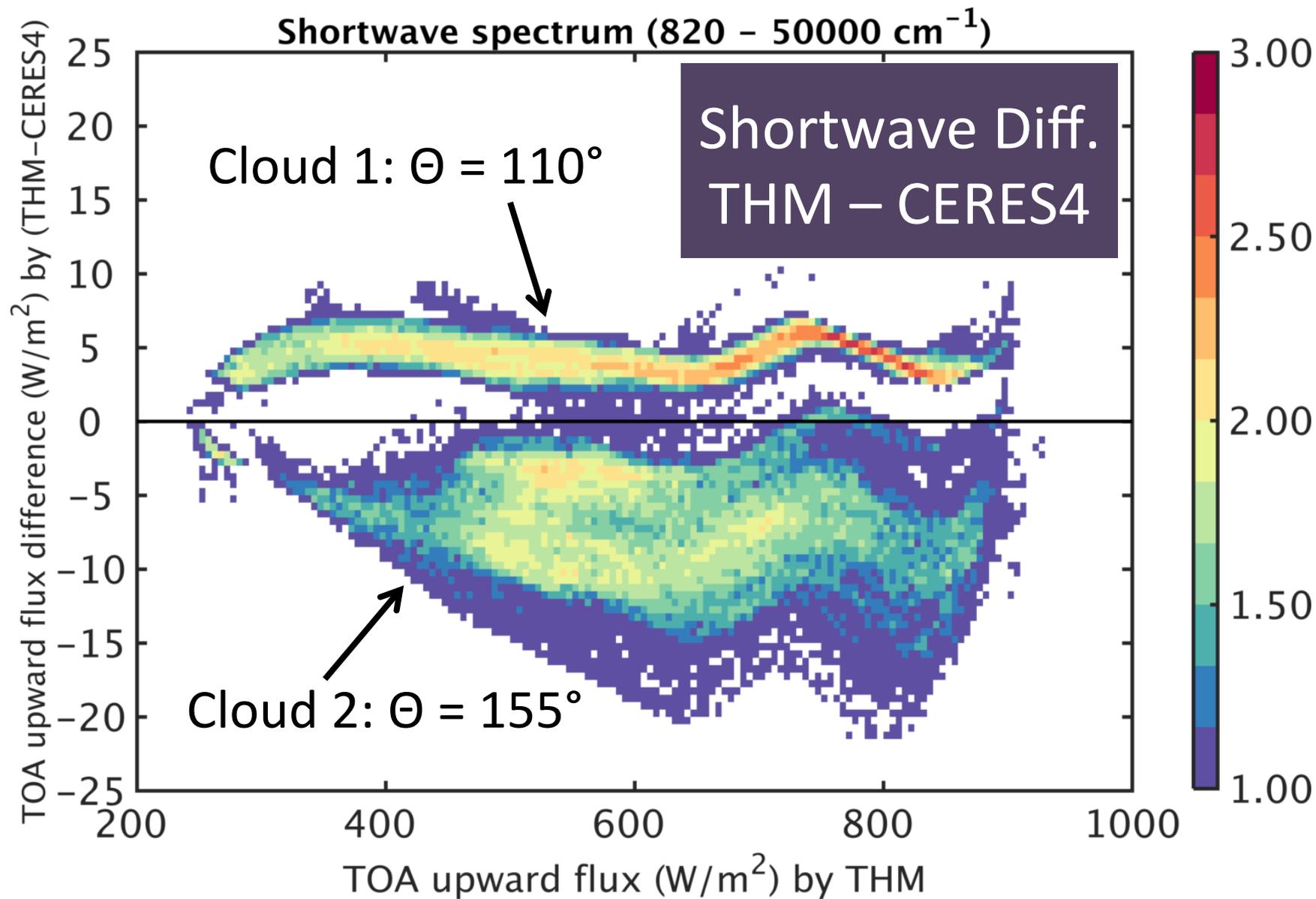


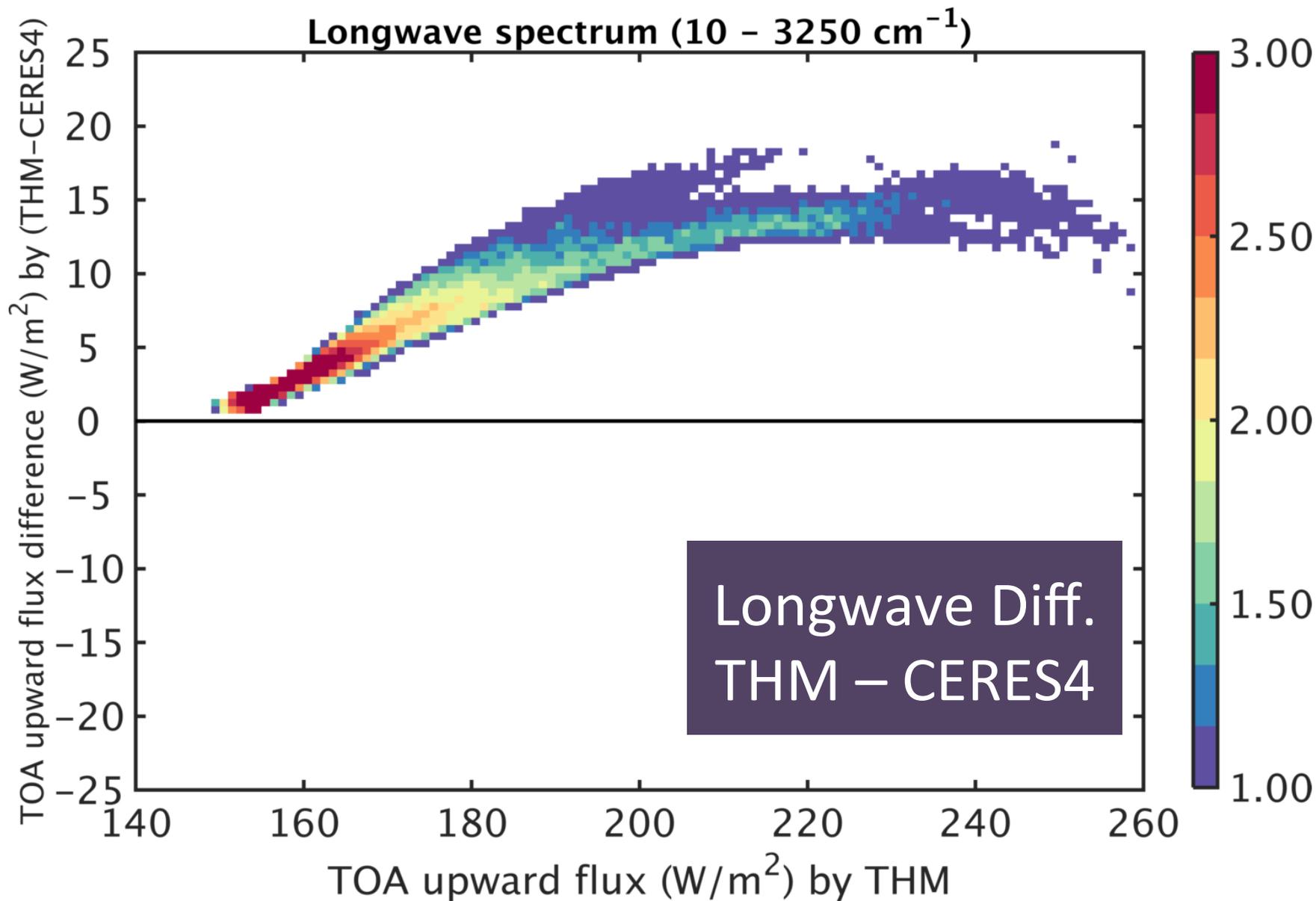




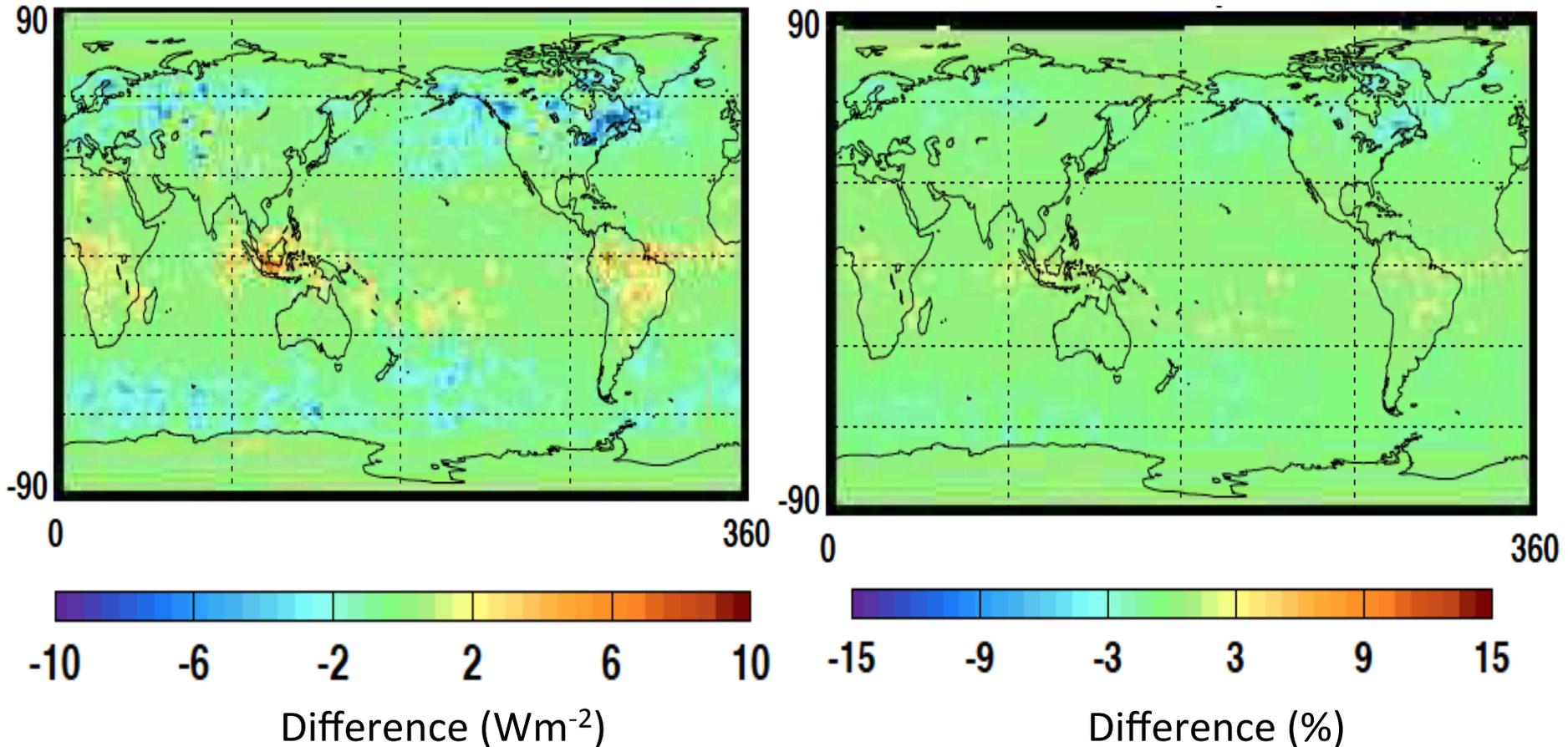


Granule: Terra 2013258.0100, Band 2 (0.865 μm) and Band 7 (2.13 μm)





SW TOA Flux Difference at Aqua Overpass Time ($\text{THM}(\text{Ret})/\text{THM}(\text{Fwd})$ minus $\text{Smooth}(\text{Ret})/\text{Smooth}(\text{Fwd})$)

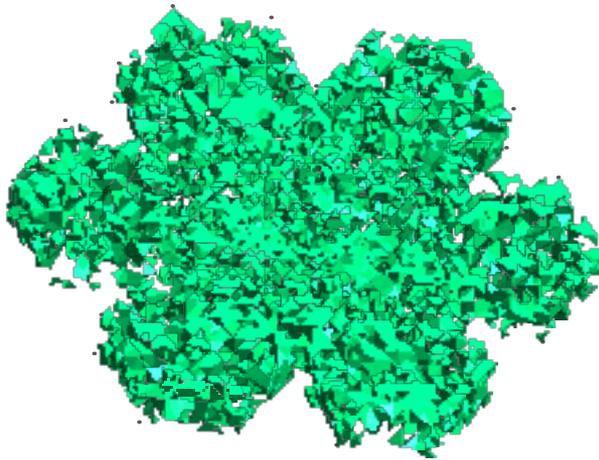


- Overall regional RMS difference is $\sim 1\%$. However, in some locations regional differences reach 3%.
- Differences tend to be positive in tropics and negative in midlatitudes.

N. Loeb et al. (2016)

Bicontinuous medium technique (Xu and Tsang, 2012) for snow particles

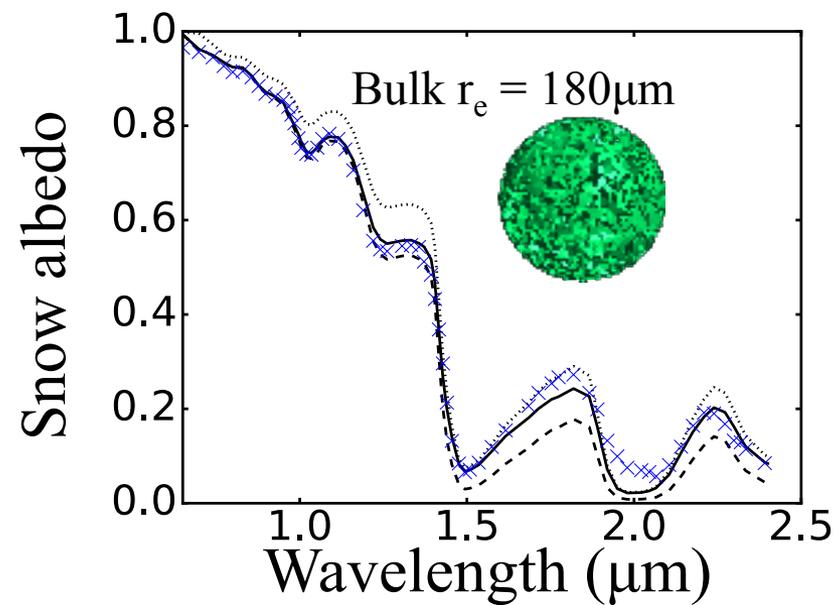
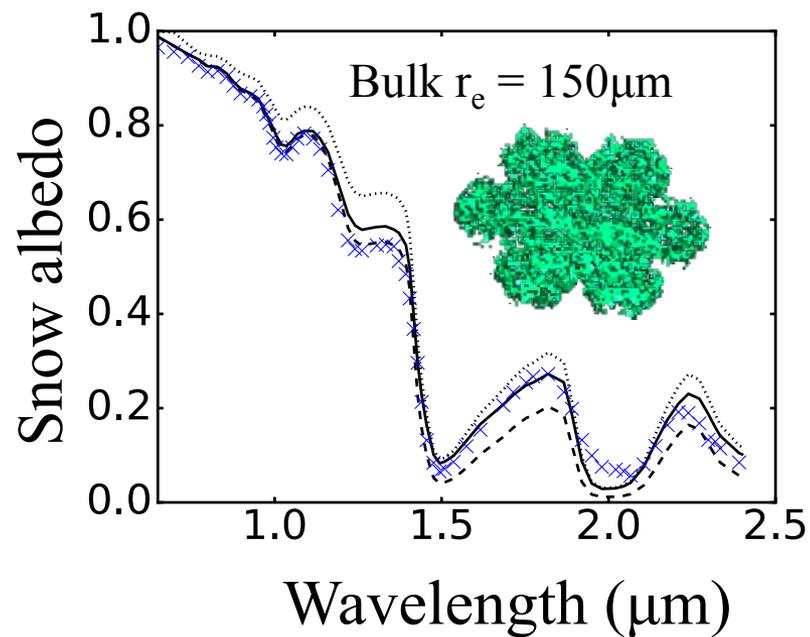
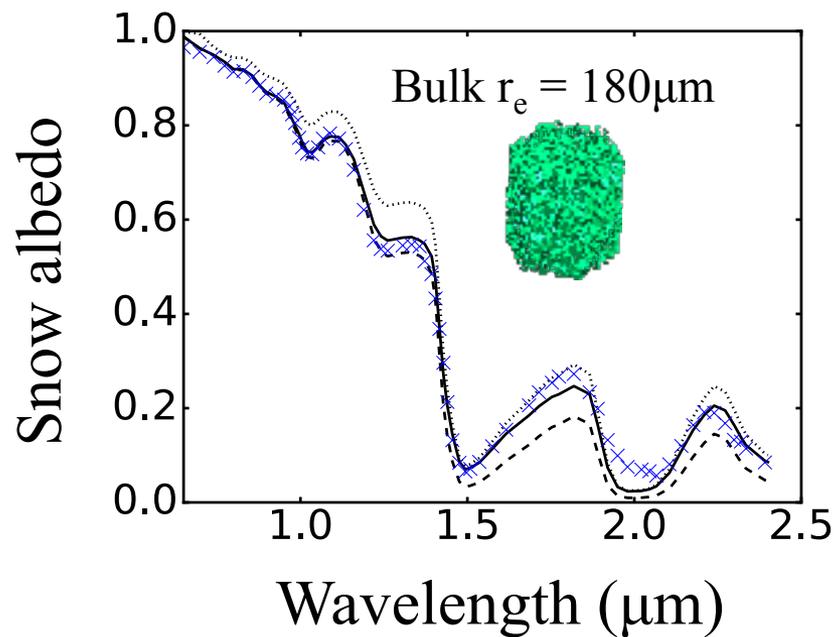
Courtesy of K. G. Libbrecht



$$S(\bar{r}) = \frac{1}{\sqrt{N\langle A^2 \rangle}} \sum_{n=1}^N A_n \cos(\bar{k}_n \cdot \bar{r} + \phi_n)$$

$$\Theta_\alpha(S(\bar{r})) = \begin{cases} 1 & \text{for } S(\bar{r}) > \alpha \\ 0 & \text{otherwise} \end{cases}$$

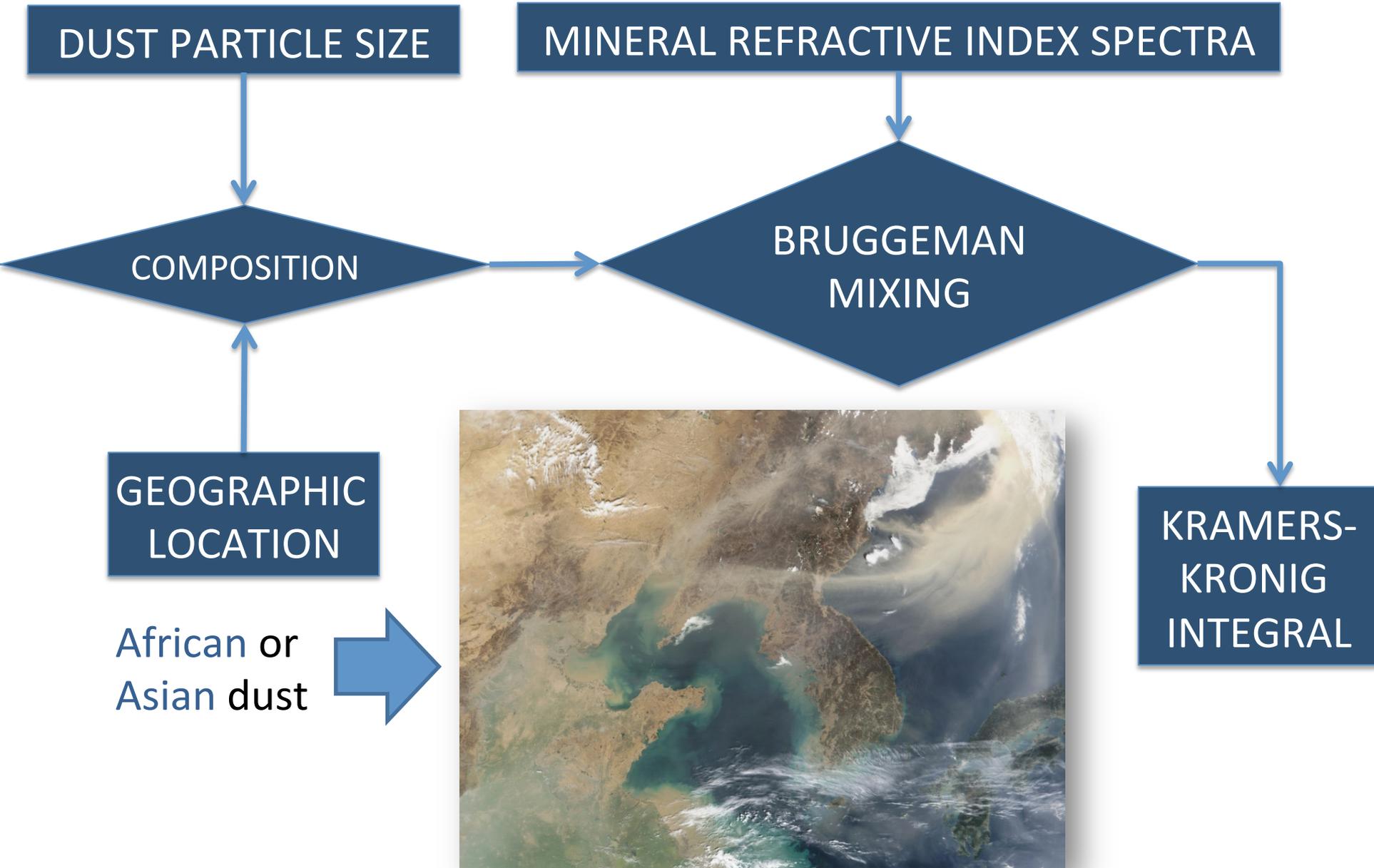
Snow albedo (diffuse illumination) simulation



- Density = $0.2\rho_{\text{ice}}$
- · - · Density = $0.5\rho_{\text{ice}}$
- Density = $0.2\rho_{\text{ice}}/0.5\rho_{\text{ice}}$
- × × Observation (Hudson 2006)

Dust Simulations

DUST MODEL OVERVIEW



The screenshot displays a terminal window with the following code and output:

```
python E:\...
Warning in pixReadMemPng: work-around: writing to a temp file
=====output=====

python E:\...
Warning in pixReadMemPng: work-around: writing to a temp file
Error in pixGenHalfToneMask: pix too small: w = 77, h = 1439
Detected 3 diacritics
=====output=====

python E:\...
Warning in pixReadMemPng: work-around: writing to a temp file
Warning in pixReadMemPng: work-around: writing to a temp file
Error in pixGenHalfToneMask: pix too small: w = 88, h = 1462
=====output=====

0.751 I
```

The table on the left is titled "TABLE I (Continued) Calcium Carbonate (Calcite)" and lists optical properties for various wavelengths. The columns are labeled λ (nm), n_o , k_o , and n_e .

λ (nm)	n_o	k_o	n_e
80171.6	0.1698	2.34	0.0025 [4]
88878.0	0.1710	2.26	0.035 [1]
88479.5	0.1722	2.20	0.0066 [4]
88071.5	0.1730	2.20	0.018 [1]
87803.5	0.1746	2.20	0.0041 [4]
87264.9	0.1750	2.20	0.006 [1]
87142.9	0.1770	2.14	0.0029 [4]
86497.2	0.1771	2.14	0.0027
86458.4	0.1790	2.09	1.66
85865.9	0.1810	2.05	1.64
85651.8	0.1823	2.05	1.63
85248.6	0.1830	2.02	1.63
84845.3	0.1851	2.02	1.62
84644.8	0.1851	2.02	1.62
84054.1	0.1870	2.02	1.62
84038.7	0.1870	2.02	1.62
83475.9	0.1890	2.02	1.62
82910.1	0.1910	2.02	1.62
82356.0	0.1910	2.02	1.62
82253.8	0.19899	1.80284 [6]	1.57796 [6]
81977.5	0.20009	1.88242	1.57649
81906.9	0.20447	1.86733	1.57081
81027.0	0.20821	1.84558	1.56640
80646.3	0.20988	1.84558	1.56327
7375.9	0.21108	1.8458240 [7]	1.5599225 [7]
6630.9	0.21445	1.8307980	1.5551219
6570.5	0.21944	1.83075 [6]	1.55496 [6]
6566.4	0.22400	1.81890	1.55105
4642.9	0.22651	1.8130351 [7]	1.5491444 [7]
4147.6	0.22910	1.8023942	1.5455001
3272.2	0.23120	1.80233 [6]	1.54541 [6]
3235.8	0.24281	1.78111	1.53782
1184.5	0.24459	1.7796645 [7]	1.5373101 [7]
8885.4	0.25031	1.76968 [6]	1.53358 [6]
8946.8	0.25731	1.7605000 [7]	1.5301212 [7]
8663.3	0.25732	1.76038 [6]	1.53005 [6]
8602.6	0.26320	1.75343	1.52736
7993.9	0.26761	1.74864	1.52547
7367.8	0.27487	1.7415041 [7]	1.5226617
6381.1	0.28164	1.74139 [6]	1.52261 [6]
5966.3	0.29137	1.72774	1.52018
5320.9	0.30341	1.7195881 [7]	1.51703
4997.5	0.30821	1.71657 [6]	1.5136064 [7]
4443.6	0.30821	1.71425	1.51240 [6]
3902.3			1.51140

46 Journal Articles
3 Reference Books



Optical Character
Recognition Program



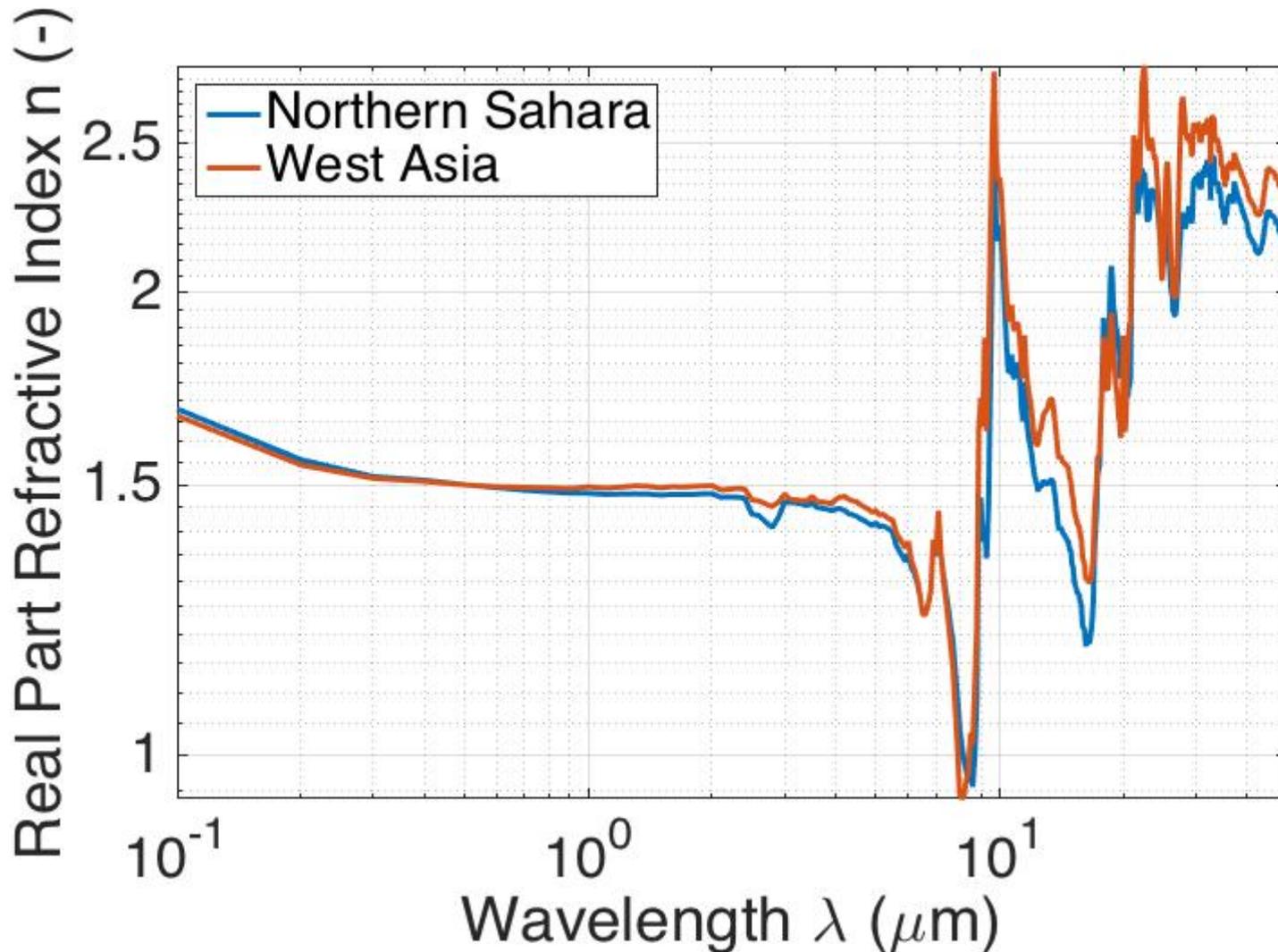
Digital Data

The Kramers-Kronig relation for the index of refraction (the real part and imaginary part are NOT independent)

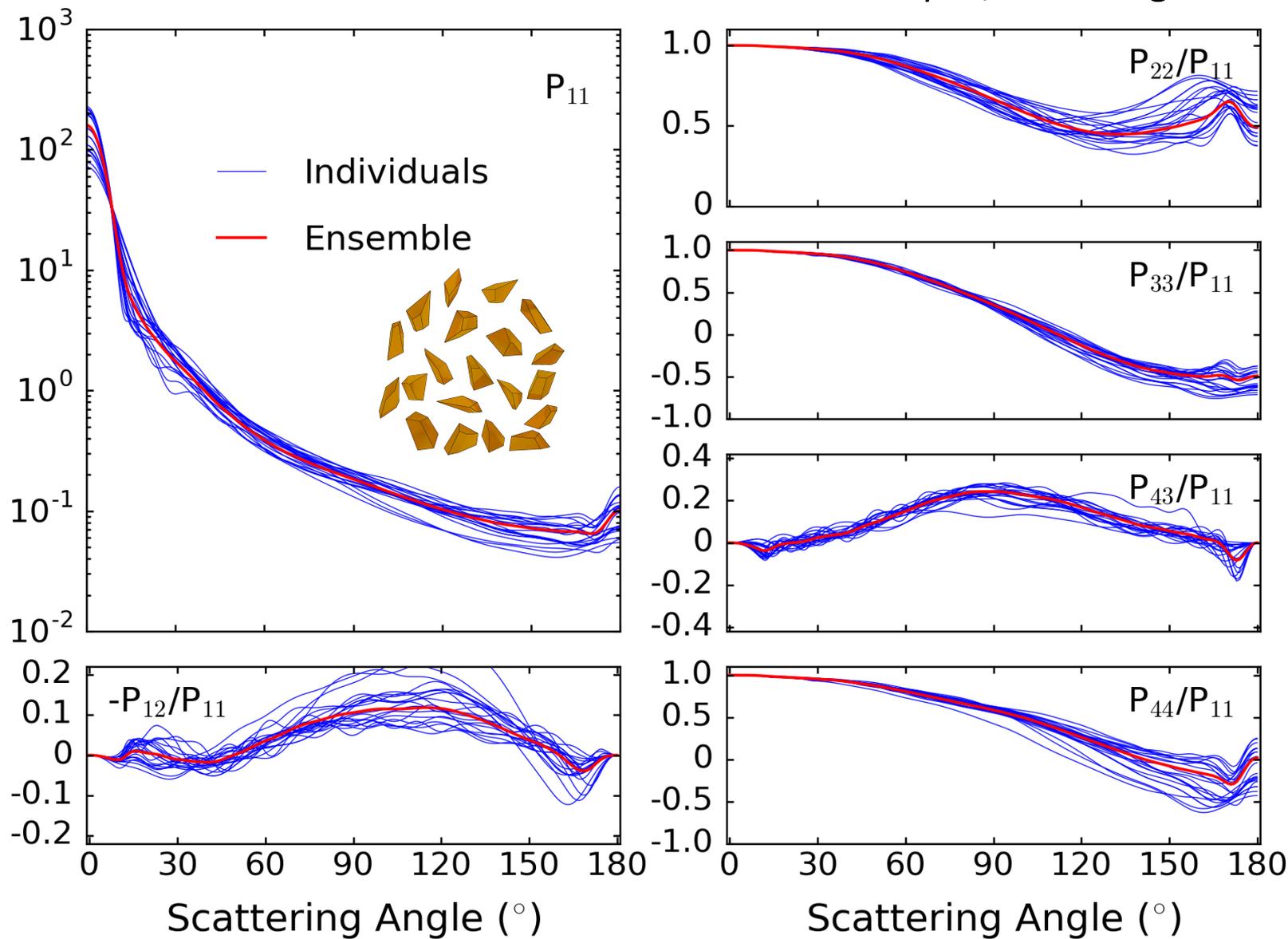
$$\operatorname{Re}[\varepsilon(v)] = 1 + \frac{2}{\pi} \text{P} \int_0^{\infty} \frac{v' \operatorname{Im}[\varepsilon(v')]}{v'^2 - v^2} dv',$$

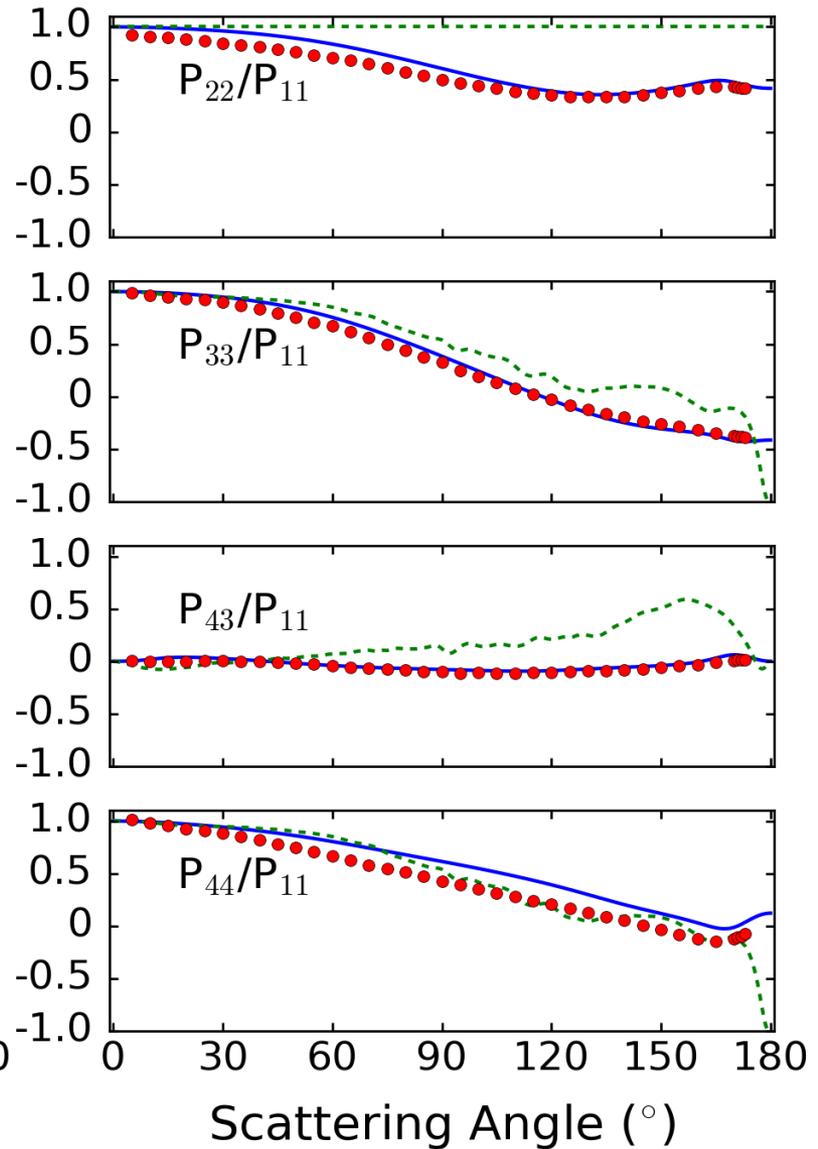
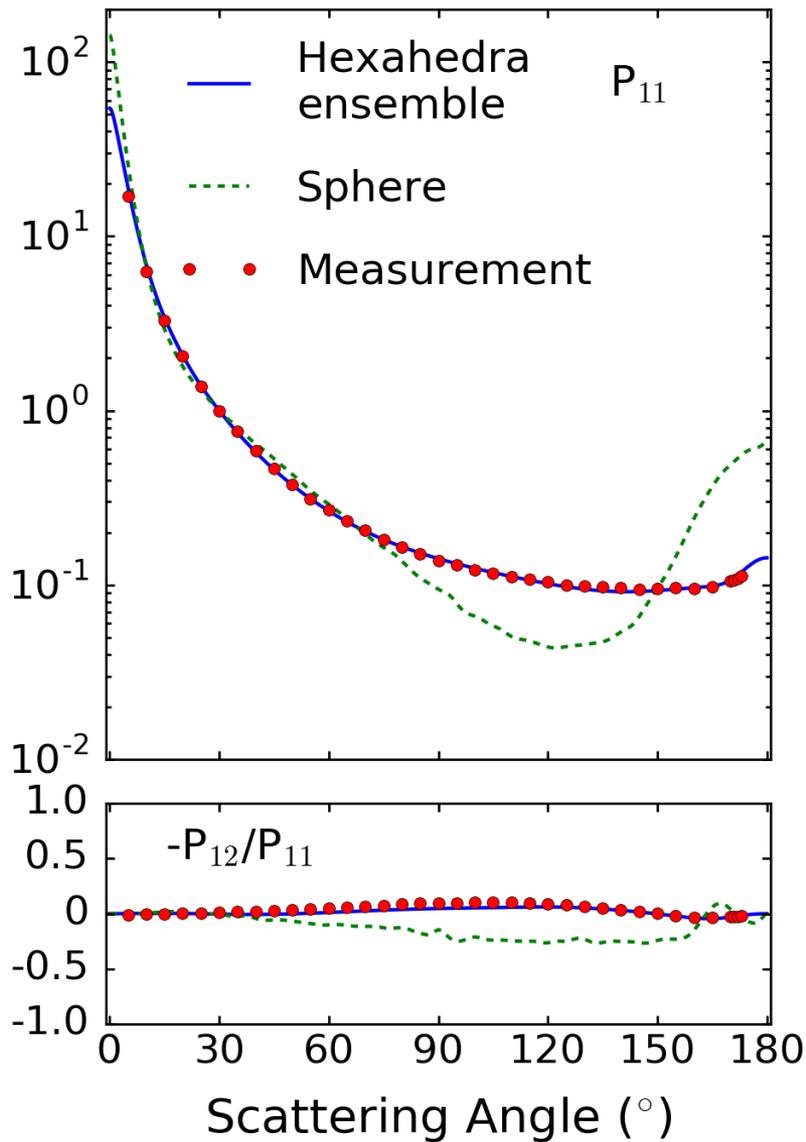
$$\operatorname{Im}[\varepsilon(v)] = -\frac{2v}{\pi} \text{P} \int_0^{\infty} \frac{\operatorname{Re}[\varepsilon(v')] - 1}{v'^2 - v^2} dv',$$

Computed refractive index of dust from the Northern Sahara, and West Asia (Gobi desert). The particle size is $15\ \mu\text{m}$.



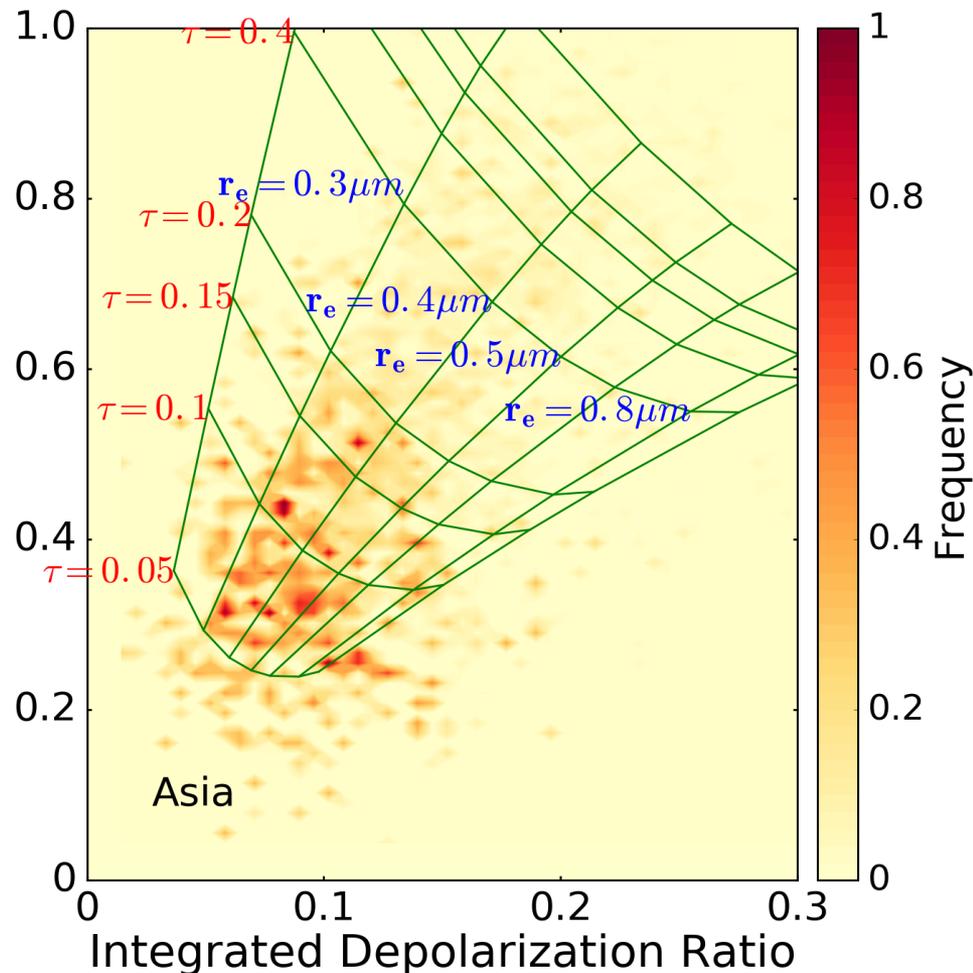
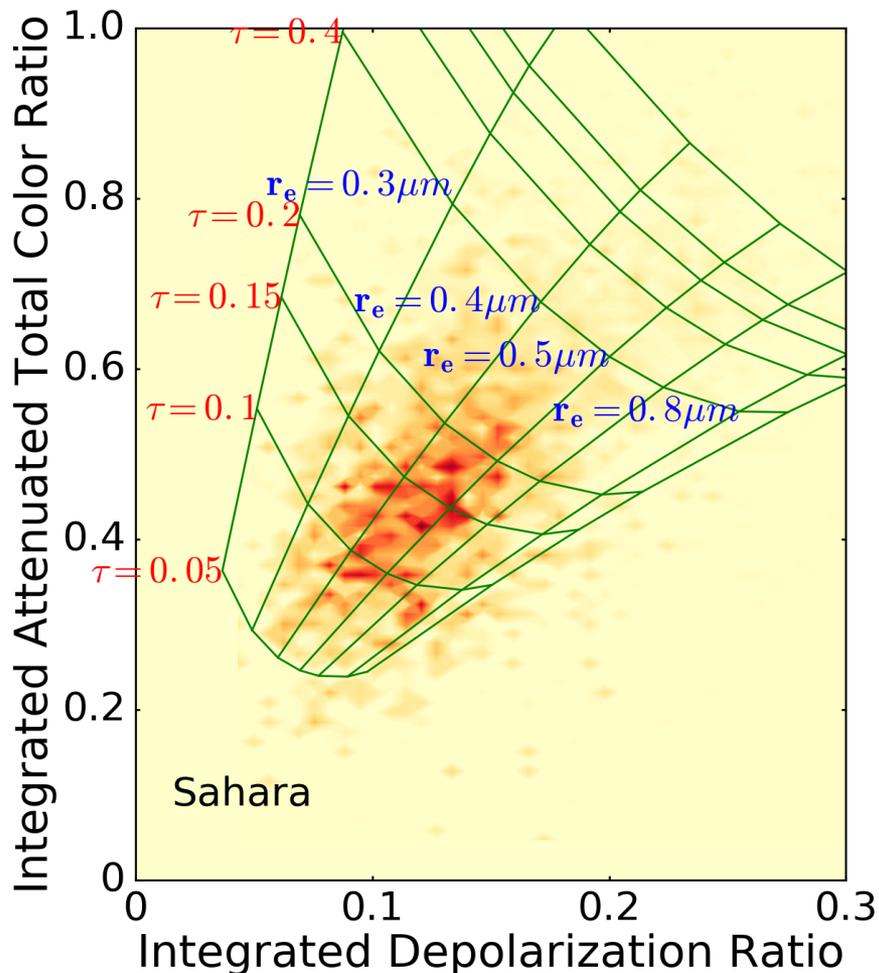
maximum dimension = $8.6 \mu\text{m}$, wavelength = $0.55 \mu\text{m}$





Phase matrices at 632.8 nm of **hexahedra ensemble** and **sphere** models compared with **olivine measurement** in Amsterdam light scattering database

Comparison of Integrated depolarization ratio (IDR) and integrated color ratio (ICR) relations between **CALIOP data (contour)** and **simulation (green curve)** for various AOT (τ) and effective radius (r_e). **Left: Saharan dust; Right: Asian dust**



Summary

- The overall performance of the new two-habit model (THM) for ice clouds is similar to that of the MODIS C6 model.
- Significant progress has been made in modeling the optical properties of surface snow by using the bi-continuous medium technique, which will be incorporated into the Langley radiation model.
- A new database of the optical properties of African and Asian dust is under development.